



Polymeric Materials for Aerospace Power and Propulsion- NASA Glenn Overview

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Use of lightweight materials in aerospace power and propulsion components can lead to significant reductions in vehicle weight and improvements in performance and efficiency. Polymeric materials are well suited for many of these applications, but improvements in processability, durability and performance are required for their successful use in these components. Polymers Research at NASA Glenn is focused on utilizing a combination of traditional polymer science and engineering approaches and nanotechnology to develop new materials with enhanced processability, performance and durability. An overview of these efforts will be presented.



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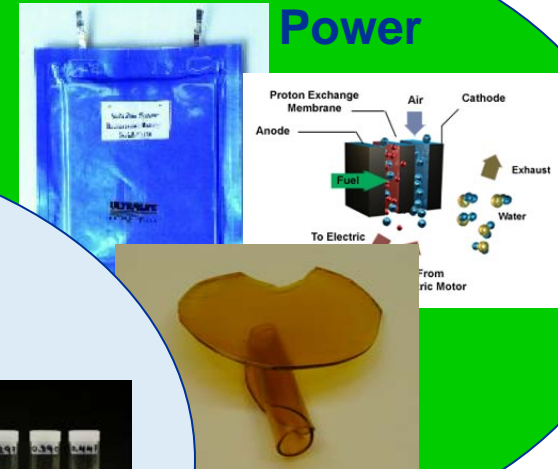


Polymers Branch R&D Efforts

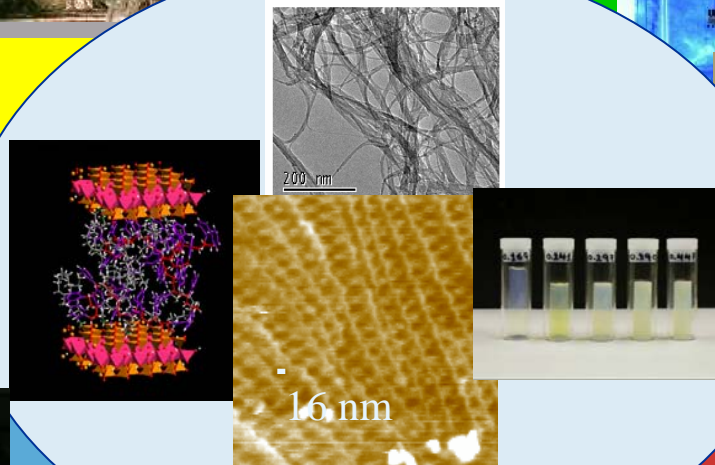
Propulsion



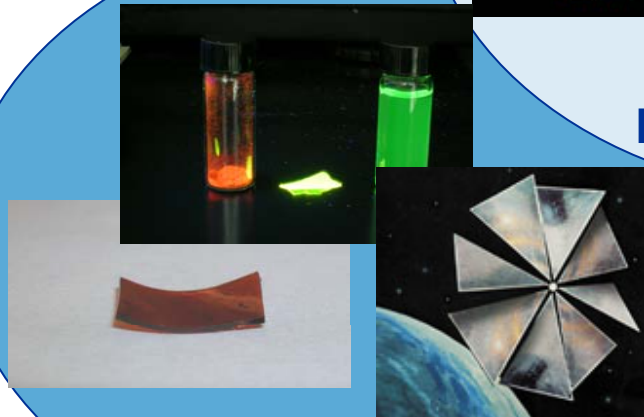
Power



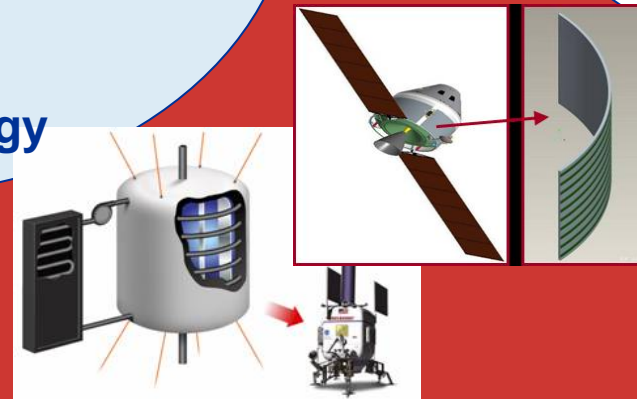
Nanotechnology



Stimuli Responsive Materials



Thermal Control Materials





GRC Polymeric Materials Research Efforts in Aeronautics

- Subsonic Rotary Wing Aircraft
 - Multifunctional acoustic insulation – gearbox noise
- Subsonic Fixed Wing Aircraft
 - Multifunctional materials for acoustic lines for aircraft engine
 - Adaptive materials
- Supersonics
 - RTM processable 600°F resins for bypass ducts and containment systems, includes nanocomposites
 - High temperature containment (500-600°F)
- Hypersonics
 - Thermal protection systems
 - High temperature ballutes – Mars landing
- Aging Aircraft
 - Effects of aging on ballistic impact behavior of composites



RTM/RFI Processable Polymers for Propulsion Components

Objective:

Develop low melt viscosity polymers for RTM, VARTM or RFI processing of high temperature propulsion components

- Melt viscosities below 20Poise
- T_g and TOS suitable for use from 500-600°F

Approach:

- Modify oligomer chemistry to reduce viscosity with minimal effect on T_g and TOS
 - Molecular morphology – branching, twists, asymmetry
 - Formulated molecular weight
 - Endcap chemistry
- Investigate use of nanoscale fillers to enhance TOS and properties

Partners:

Boeing, Clark Atlanta U, M&P Technologies



RFI Processed HFPE Panel

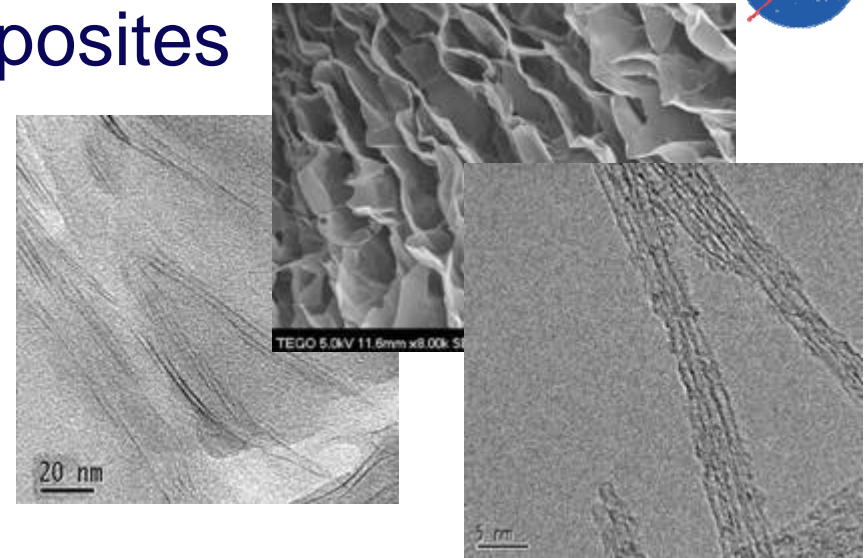


**RTM Processed
PR-520 LH2 Duct**

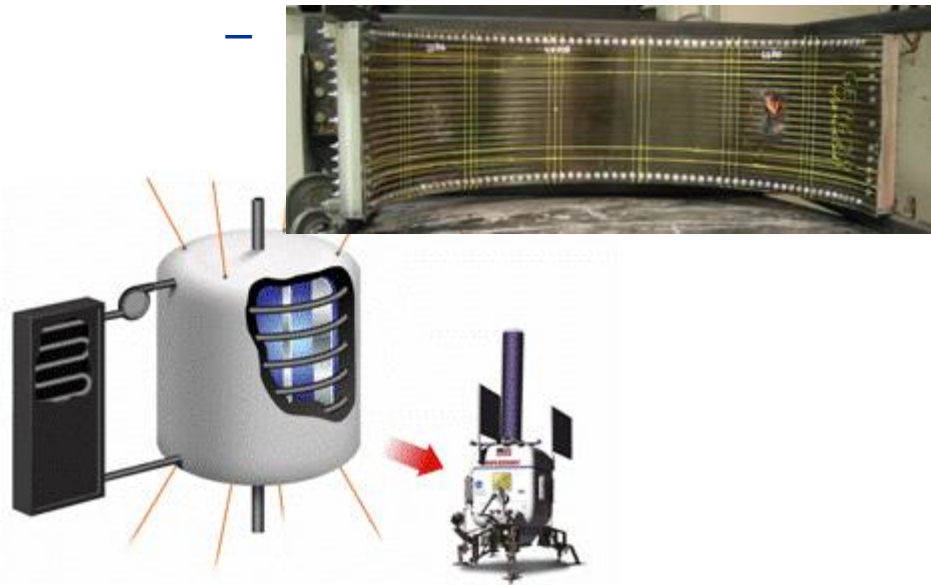


Nanocomposites

- Investigating effects of a variety of nanoscale fillers on properties of polymers
 - Organically modified clays
 - Functionalized graphene sheets (FGS aka TEGO)



- Potential applications:
 - Cryotanks – *reduced permeability, enhanced microcrack resistance*
 - Fan containment – *improved toughness*
 - High temperature engine structures – *improved TOS, mechanical properties*



Lebron-Colon, Miller, Gintert

Collaborations with: U of Akron, Princeton, Northwestern, MSU, Clark Atlanta U



Multicomponent Nanocomposites

Layered silicate clays:

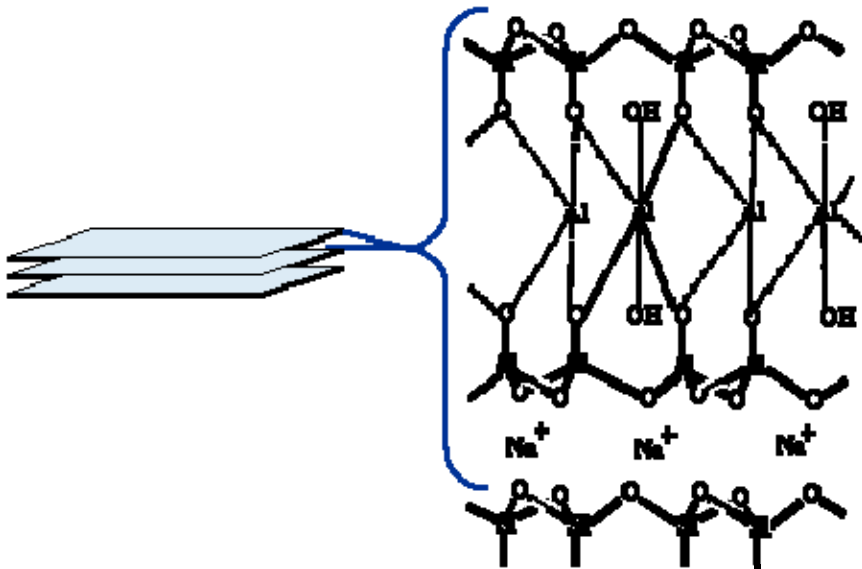
Platelet morphology provides barrier to oxygen diffusion and oxidative degradation.

Exfoliated morphology optimizes permeability reduction.

Commonly modified with alkyl ammonium ion

Degrades at polyimide processing temp.

Thermally stable modifier is necessary.

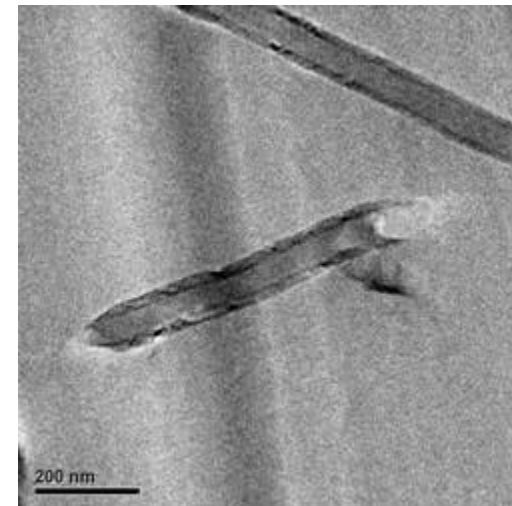


Carbon nanofibers:

Thermally stable- will not contribute to resin degradation

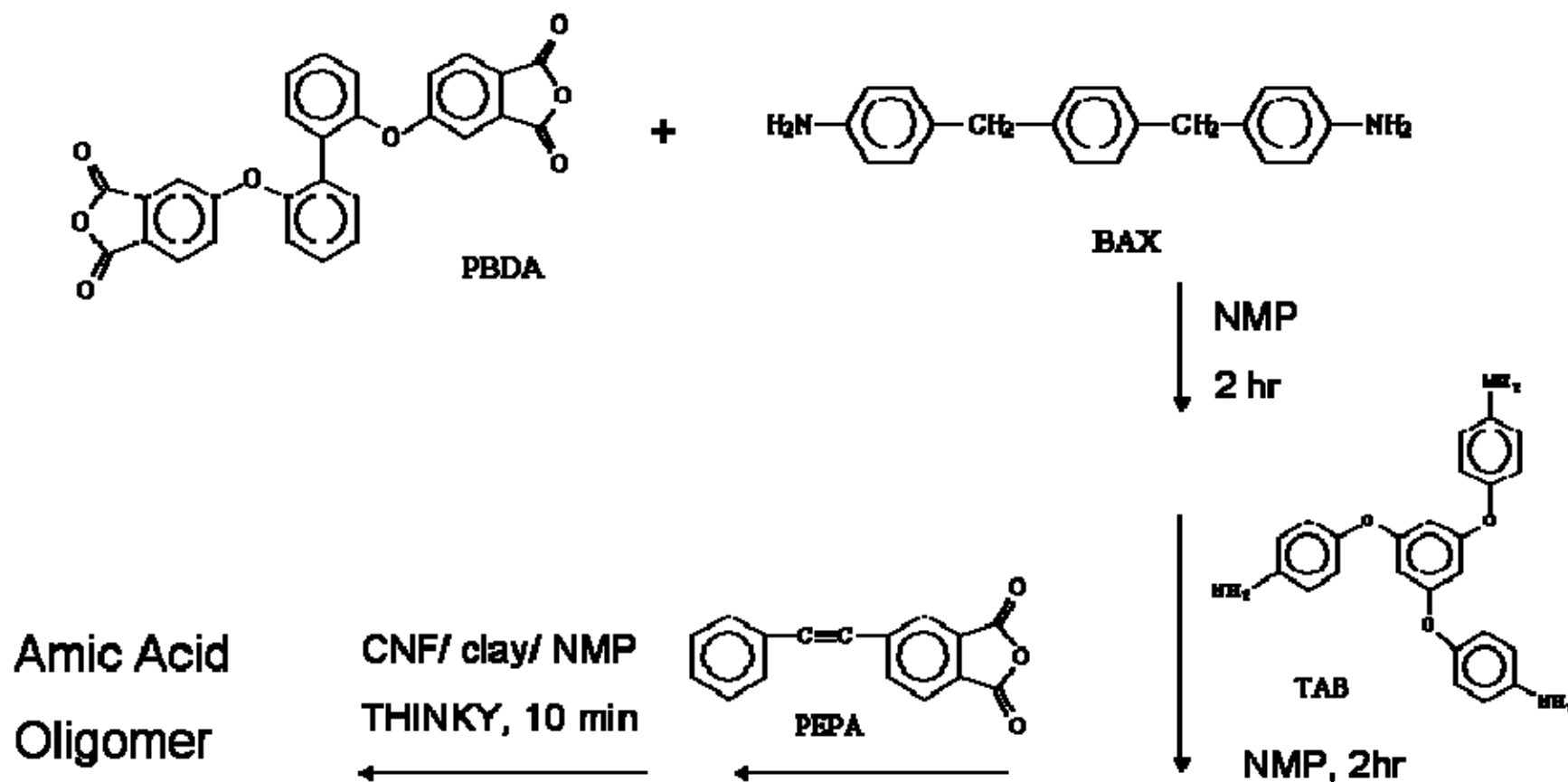
Imparts mechanical strength and stiffness to the resin.

Thermally conductive





Nanocomposite Synthesis



Clay loading: 5 wt%, CNF loading: 0.5 – 1.0 wt%

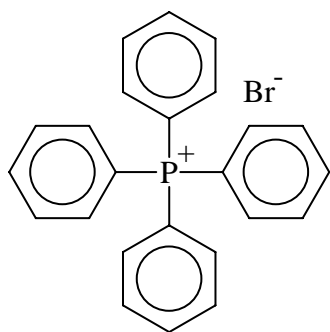


Use of Synthetic Clay Improves Resin TOS

Melt Viscosities Increase with Clay Addition

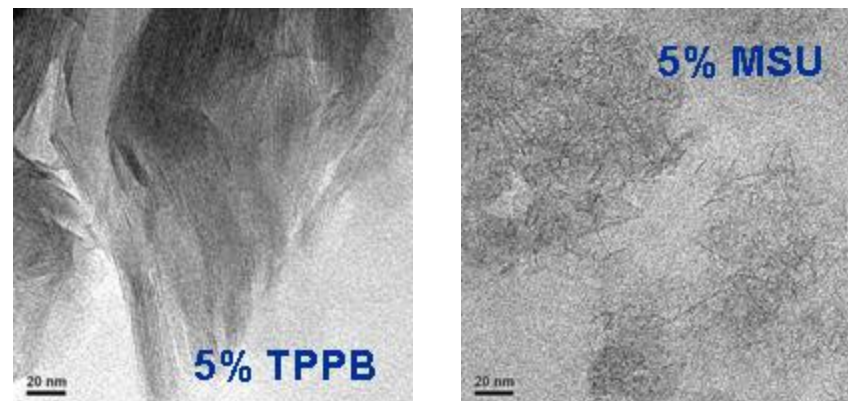
Sample	Minimum Viscosity* [cP]	Temperature (°C)
Neat Resin	~ 10	250
5% TPPB	~ 60	250
5% MSU	~ 40	250

*Measured by Brookfield

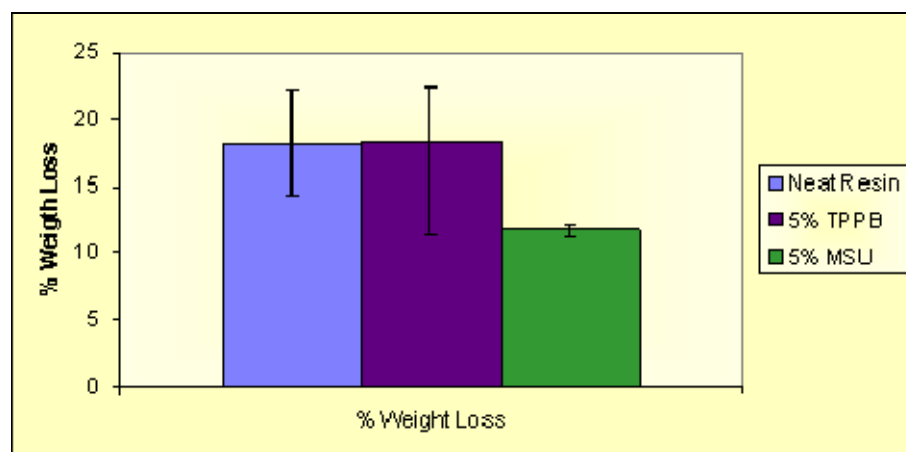


- Examined TPPB modified MMT and synthetic clay
- Used BAX-TAB RTM processable polyimide
- Evaluated TOS, melt viscosity and T_g

Pre-exfoliated Clay Gives Better Dispersion



30% Reduction in Weight Loss



Weight Loss after 1000 h at 288°C (550°F)

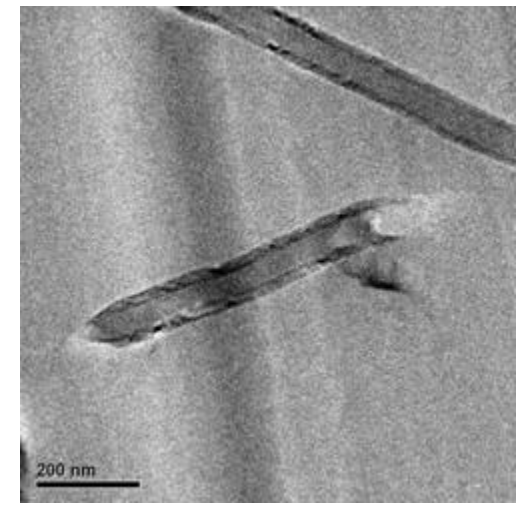
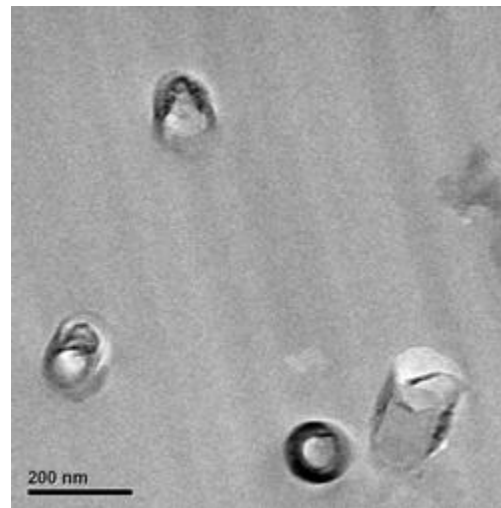
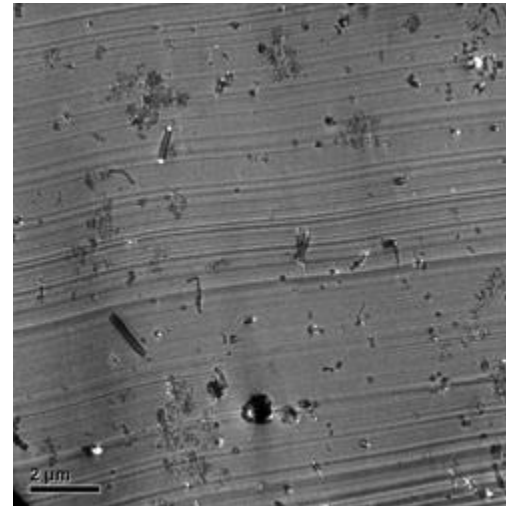


Clay and Nanofiber Dispersion

Clay and CNF dispersion
characterized by TEM

CNF separation of over
100 nm.

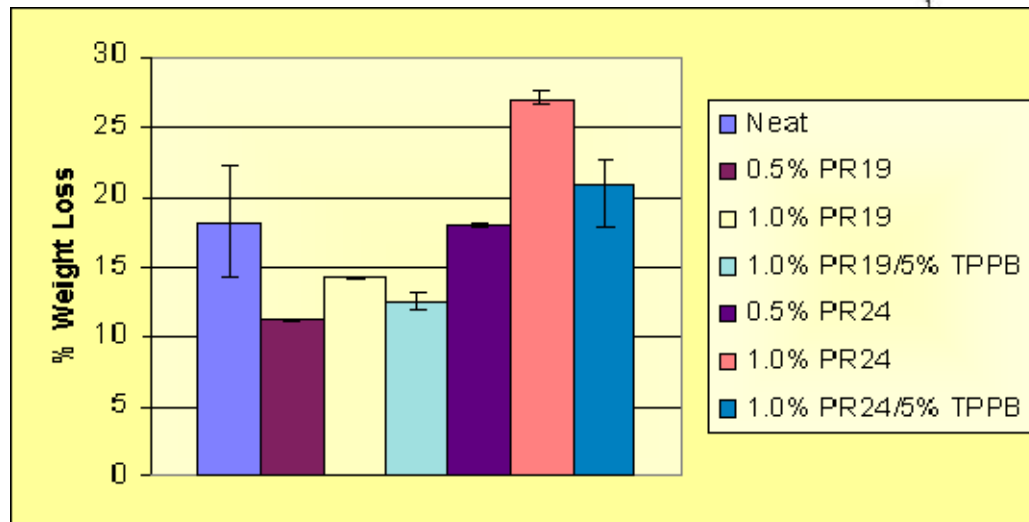
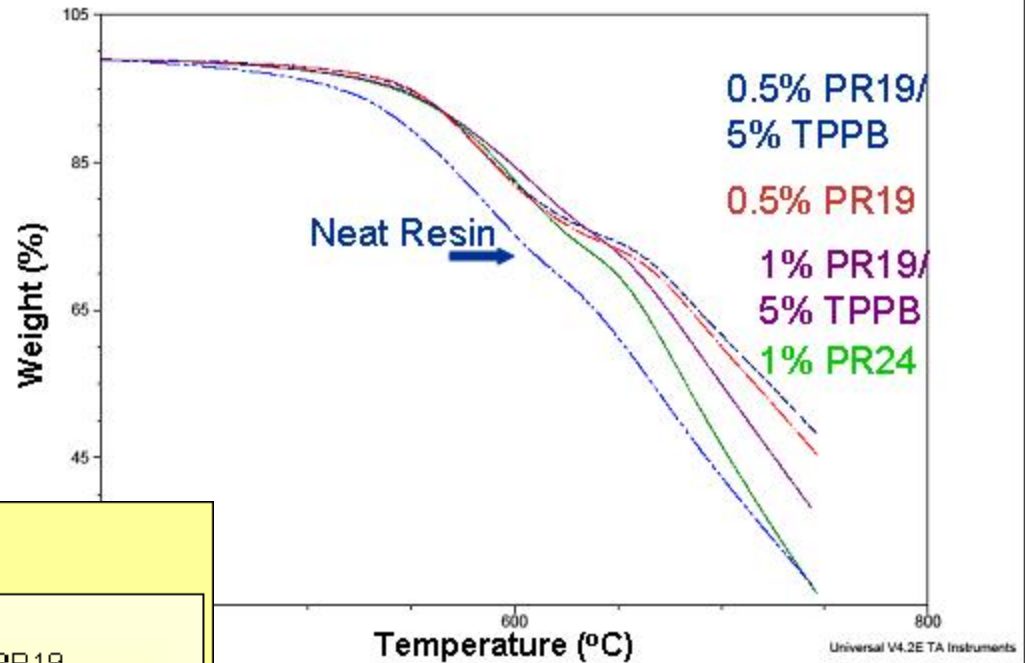
Clay dispersion
comparable to clay only
nanocomposites





Synergistic Effects of Clay and CNF Addition on Resin TOS Investigated

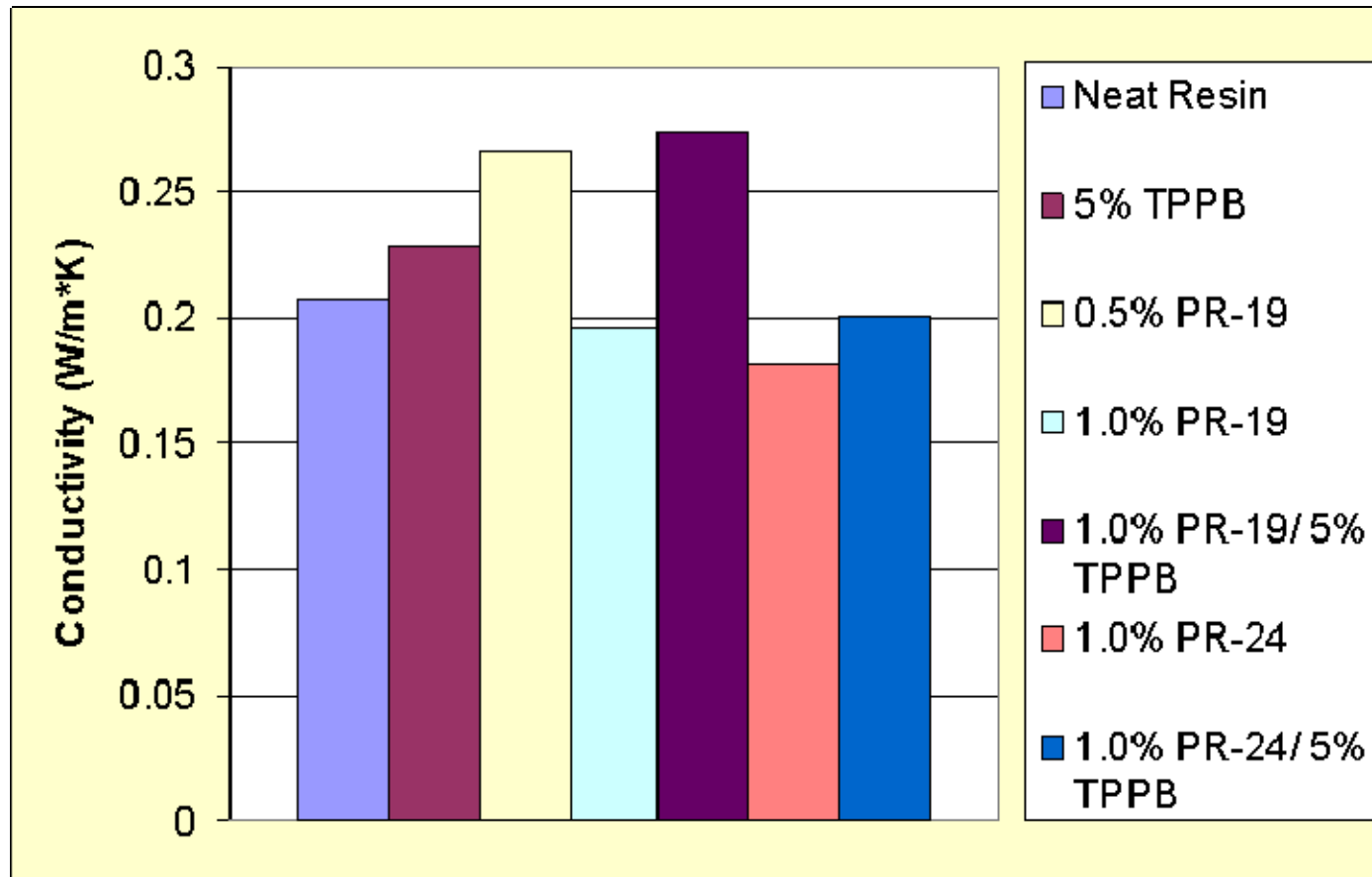
CNF containing nanocomposites increases temperature of 5% and 10% weight loss by 30°C



Nanocomposites containing PR-19 reduce polyimide weight loss on aging by up to 38%



Thermal Conductivity of CNF Nanocomposites



Increased conductivity observed in PR-19 and PR-19/TPPB nanocomposites



Effect of Nanoscale Additive on Melt Behavior

Sample	Minimum Viscosity [P]	Temp. (°C)
Neat Resin	3.5	250
0.5% PR-19	0.5	250
1% PR-19	95	250
1% PR-19/ 5% TPPB	28	250
0.5% PR-24	10	280
1% PR-24	--	--
1% PR-24/ 5% TPPB	0.78	250
5% TPPB	.04	165

Measured by Parallel Plate Rheology

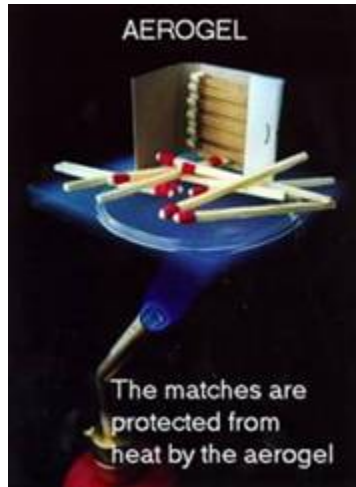


Dynamic Mechanical Analysis

Sample	Storage Modulus (MPa), 100°C	T_g (°C)
Neat Resin	1558	328
5% TPPB	1558	318
0.5% PR-19	1622	316
1% PR-19	2174	318
1% PR-19/ 5% TPPB	2351	318
0.5% PR-24	1674	323
1% PR-24	1829	315
1% PR-24/ 5% TPPB	2639	313

Increased storage modulus observed with increasing CNF concentration,
and on dispersion with clay

Durable Polymer Cross-Linked Aerogels



Conventional Aerogels

- Low densities
- High porosity and surface area
- Good electrical and thermal insulators

Application in NASA missions limited because of poor mechanical and environmental durability

Capadona, Leventis, Meador, Nguyen, Vivod

Collaborations with: Clark Atlanta, U of Akron, Parker Hannifin, ASI, Aspen Aerogels

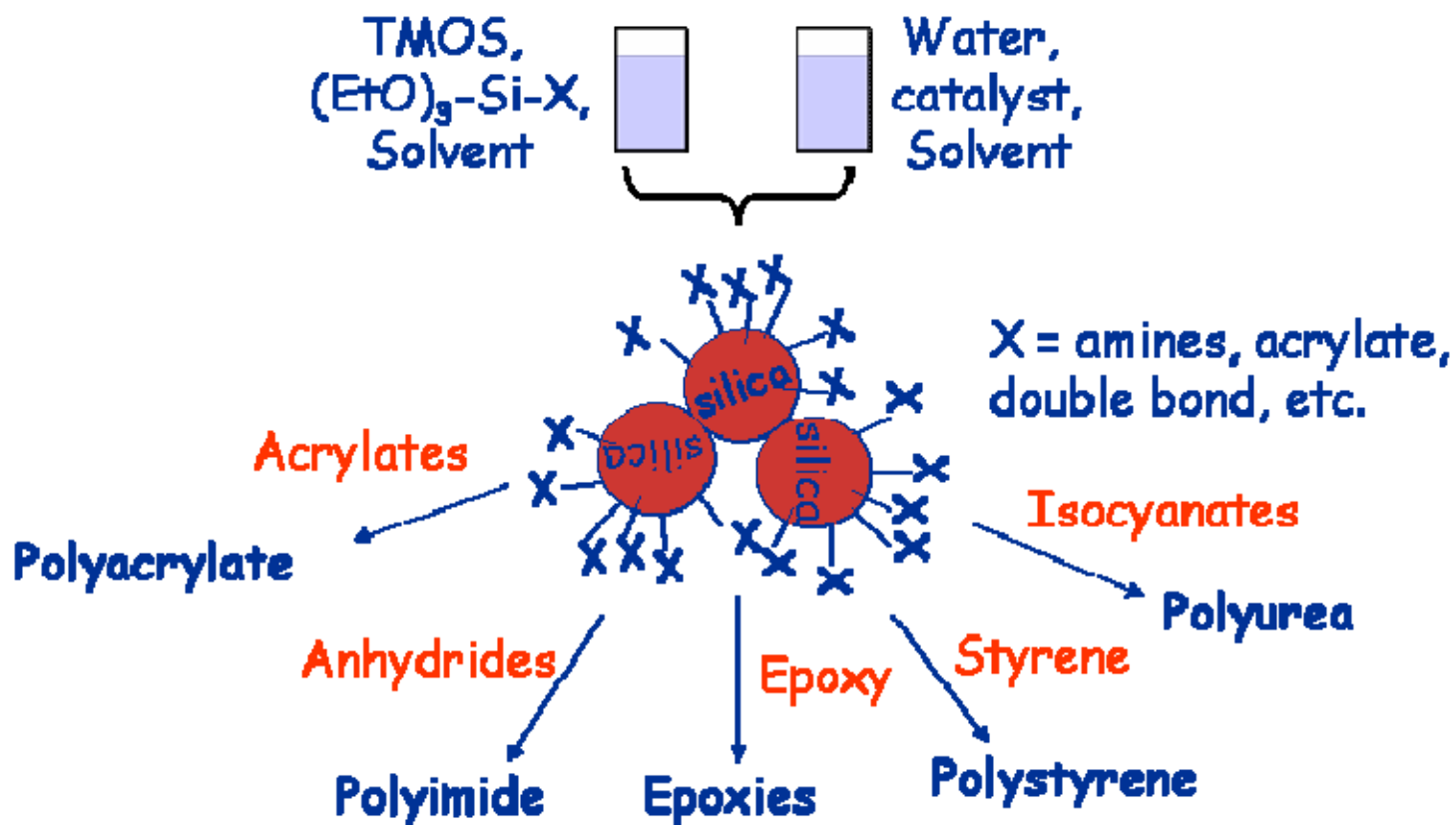
Polymer Cross-linked Aerogels

- Significantly enhanced mechanical properties (up to 300X increase in strength)
- Improved durability – some formulations are flexible
- Slightly increase in density and thermal conductivity

New aerogels offer multifunctional solution for many NASA Mission Needs

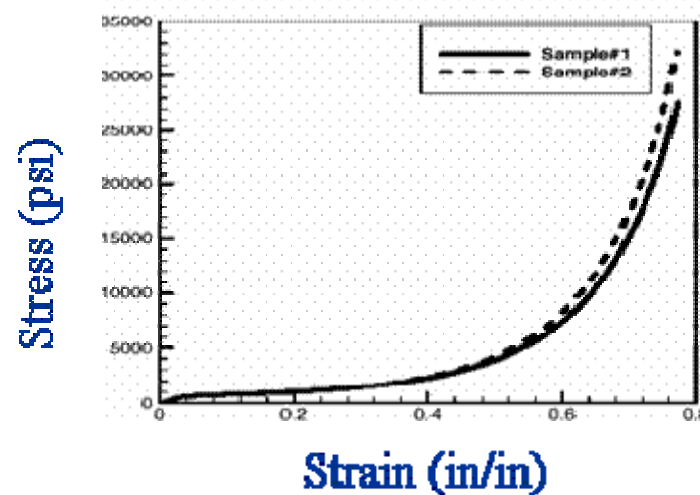
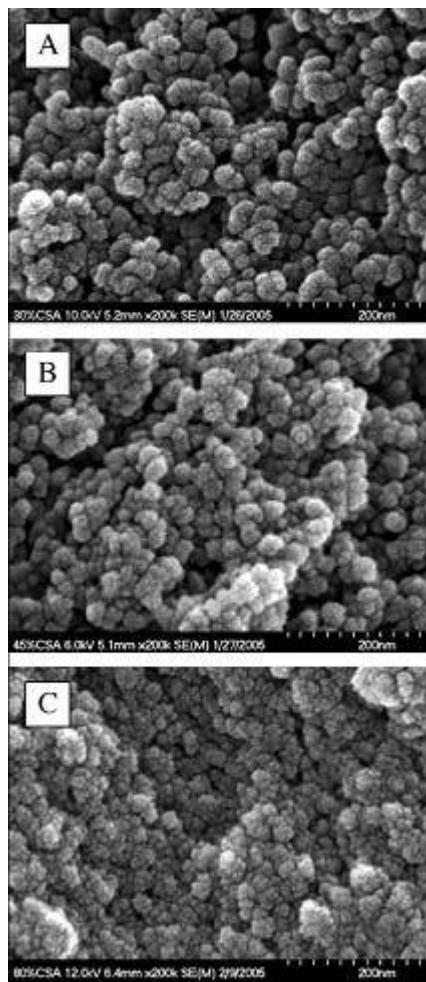


Surface Modification of Silica Particles Opens Doors to Other Polymer Systems





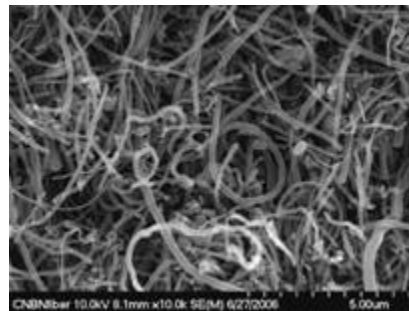
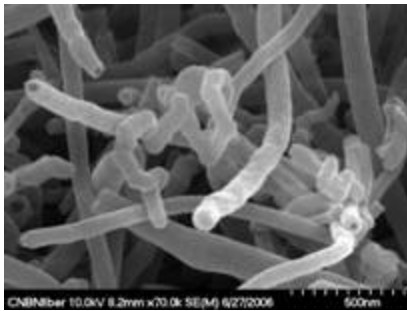
Compression test of crosslinked aerogels



Katti *et al*, *Chemistry of Materials*,
2006, 18, 285-296

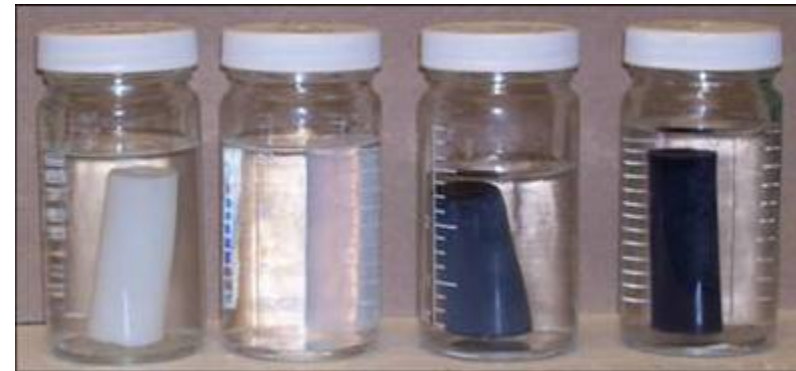


Enhanced Mechanical Properties Through the Addition of Carbon Nanofibers

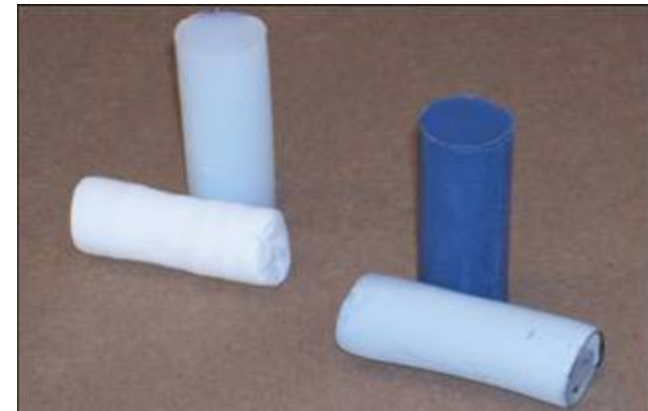


**Pyrograph® Fibers with
Proprietary Surface Treatment to
Enhance Solvent Compatibility**

- Nanofibers incorporated in the sol – form stable suspensions in acetonitrile containin APTES and TMOS
- Some fiber dissolution observed upon addition of water
- Nanofiber settling observed in gels with higher nanofiber content



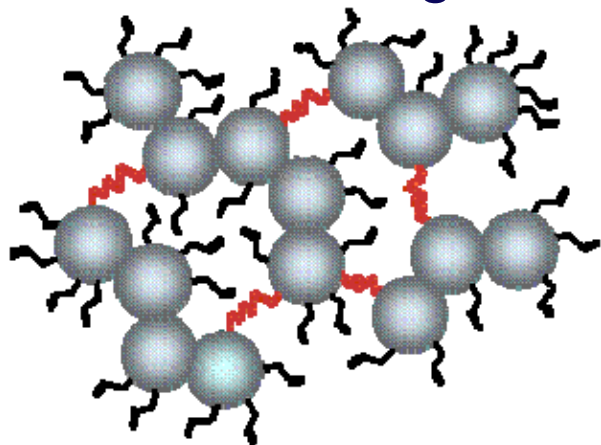
**Wet Gels with (right) and without (left)
Carbon Nanofibers**



**Dry Gels – Those with Nanofibers
Have Gray or Blue Appearance**



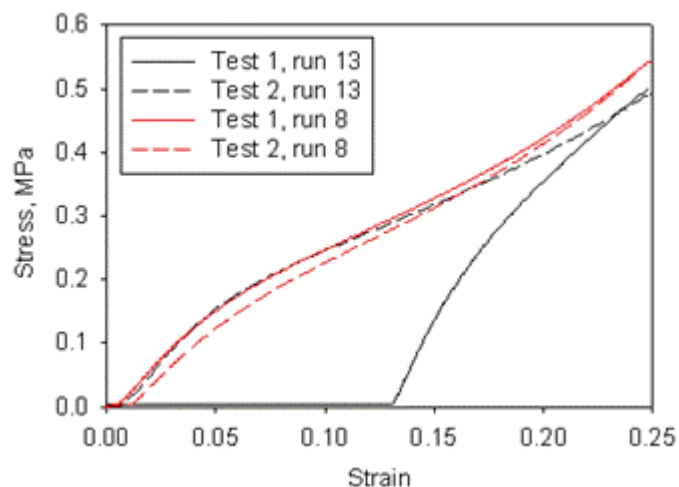
Flex-Link Aerogels Have Improved Flexibility and Durability



Incorporation of Flexible Linkages in Silica Backbone Enhances Flexibility and Durability



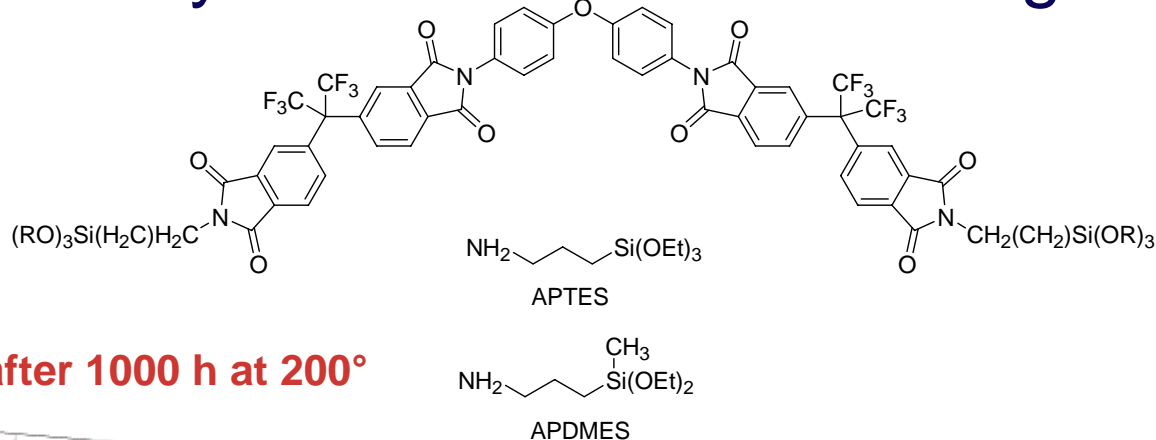
Flex-Link Aerogels Easier to Handle in “Green” State – Better Processability



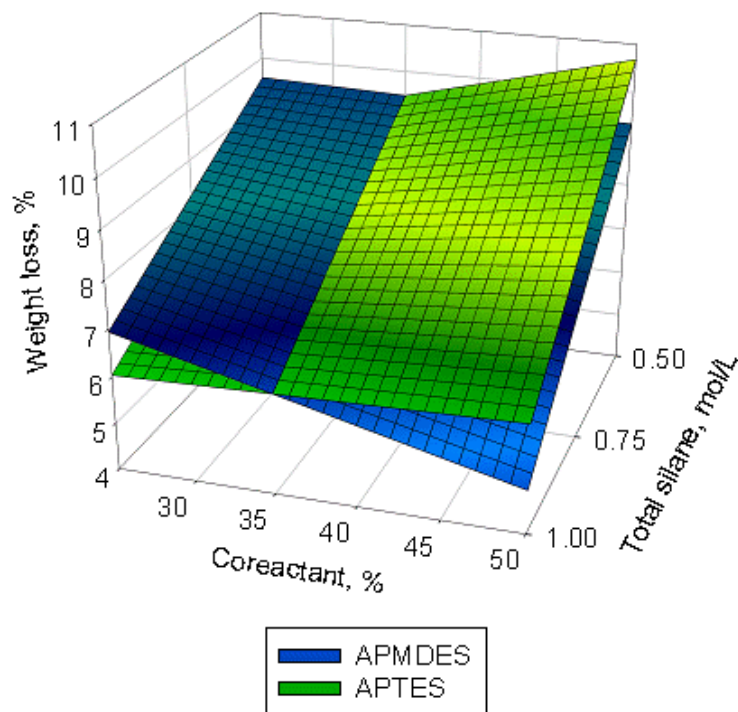
Flex-Link Aerogels Show Better Recovery After Compression



Polyimide Cross-linked Aerogels



Weight Loss after 1000 h at 200°



Corrected for weight loss due to solvent

3 Variable DoE Study to assess effects of:

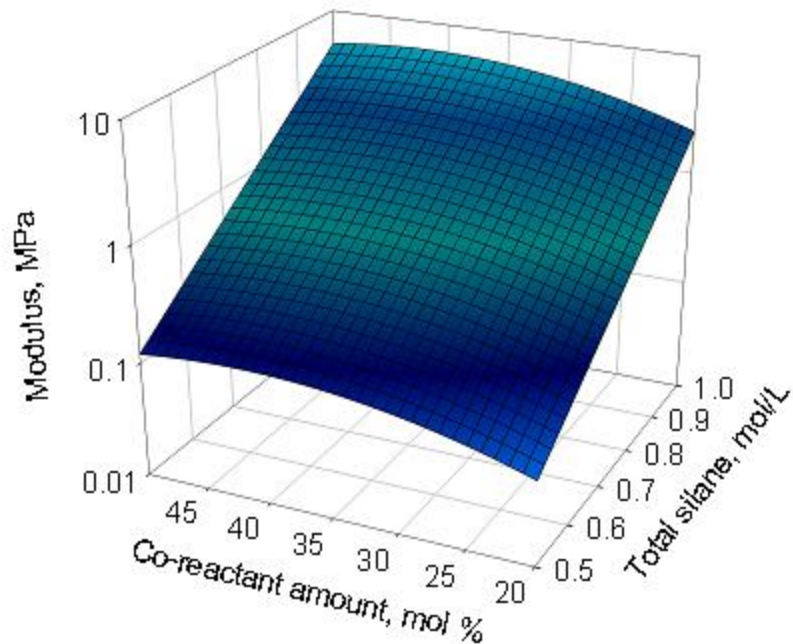
- Am't of total silane (aminopropyl + TMOS0 in initial sol)
- Two different co-reactants – APTES and APDMES
- Am't of co-reactant as mole % of total

On:

- Density – no effect of co-reactant type, interact of co-reactant and total silane
- Porosity – slightly higher for APTES
- Compressive Modulus – depends on total silane
- Compression Set – APDMES more sensitive to co-reactant %
- TOS – see figure

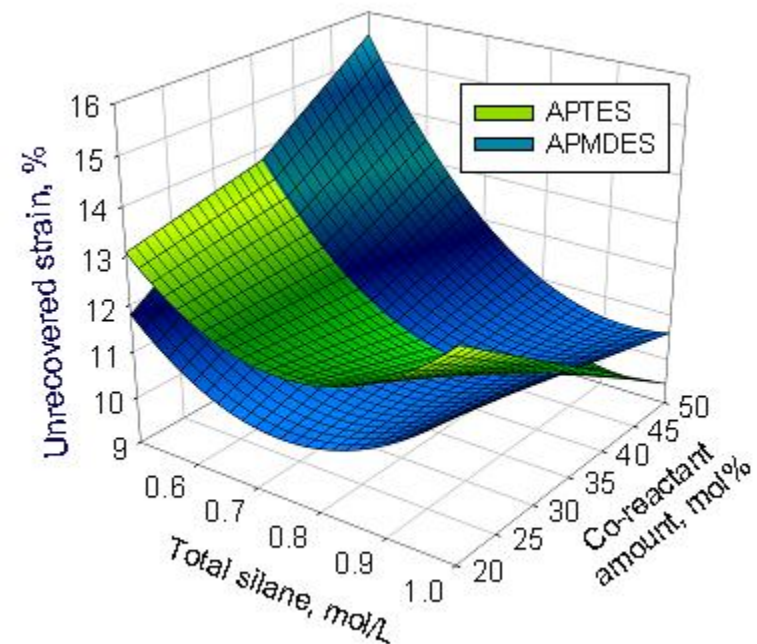


Compression tests



- Modulus dependent mostly on total silane concentration
- No effect of co-reactant type

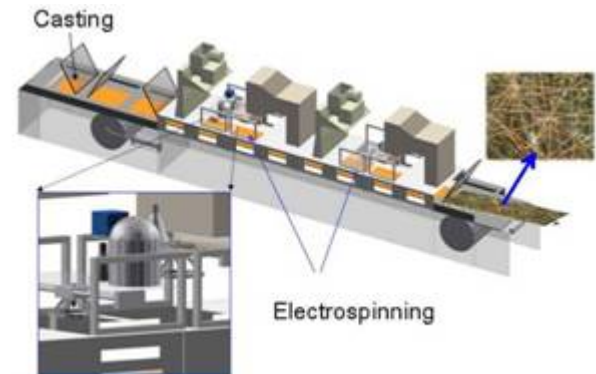
- Samples compressed to 25 % strain and allowed to recover
- APMDDES aerogels more sensitive to mole fraction





Development of large scale manufacturing

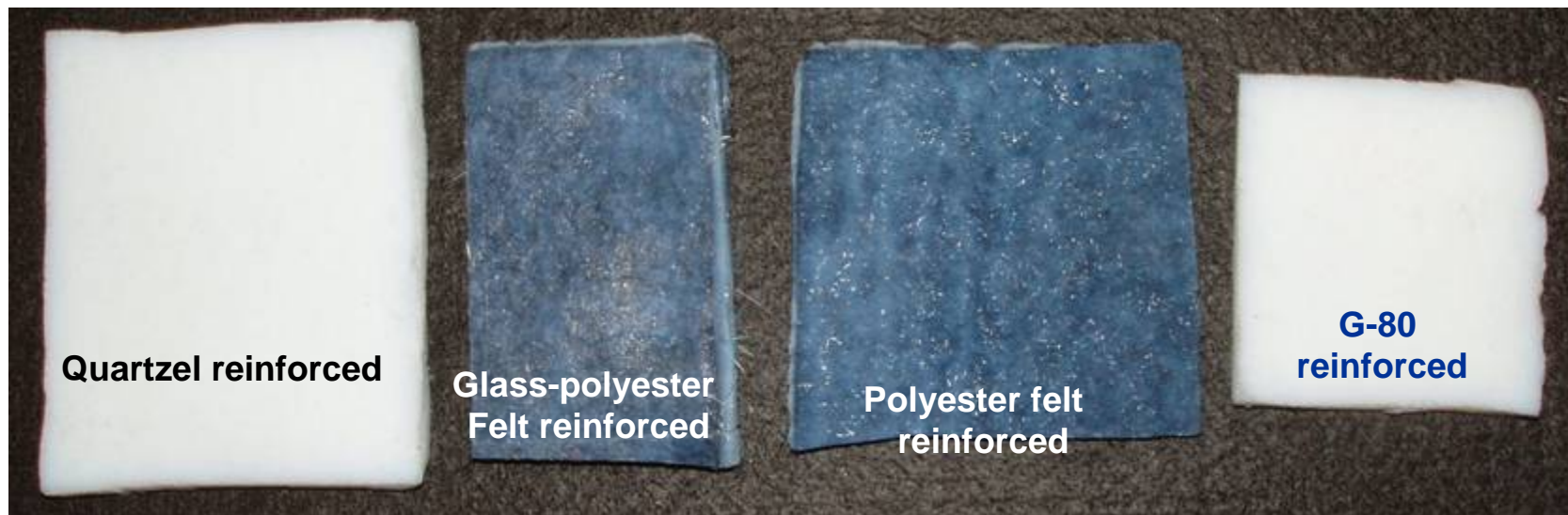
- GATE Platform Technology development
 - Parker-Hannifin
continuous process to manufacture tubing
 - University of Akron CMPD
thin film casting, incorporation
of electrospun fibers
 - Applied Sciences, Inc.
incorporation of carbon nanofibers
- Partnership with Aspen Aerogels
 - Aerogel composites
 - Early introduction technology
 - Can solve some issues
related to other types
of manufacturing





Large Scale Aerogel Manufacturing

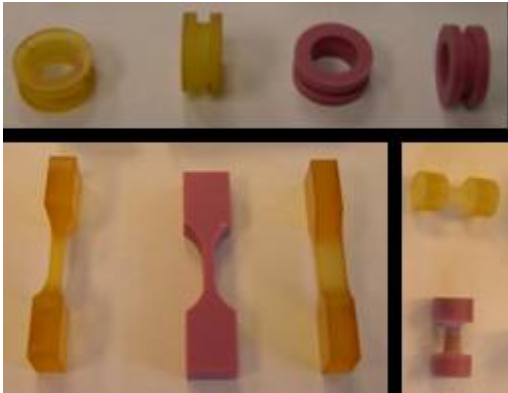
joint with Aspen Aerogels



- Thermal conductivities as low as 20mW/mK
- Mechanical properties – TBD
- Cross-linking eliminates shedding

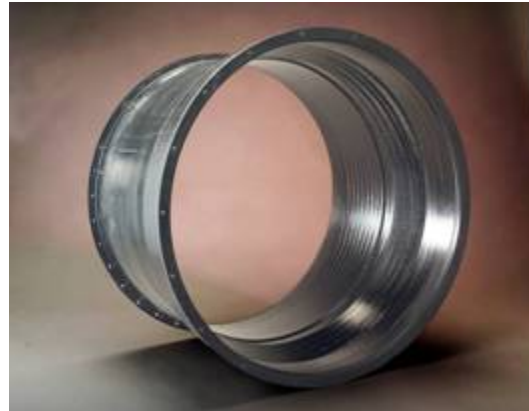


Composite Materials for Engine Containment Cases



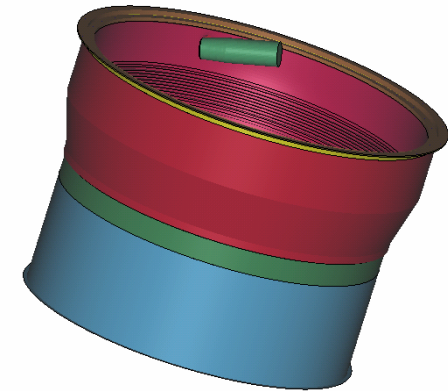
Resin Mechanical Tests

- High strain rate constitutive models
- Toughened material evaluation



Composite Fan Case Fabrication

- A&P Technology- braided preforms
- North Coast Composites- molding (RTM)



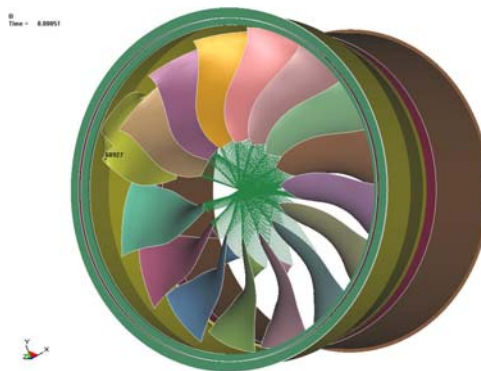
Ballistic Impact Tests: Fan Cases

- Simulate blade impact
- Measures resistance to penetration



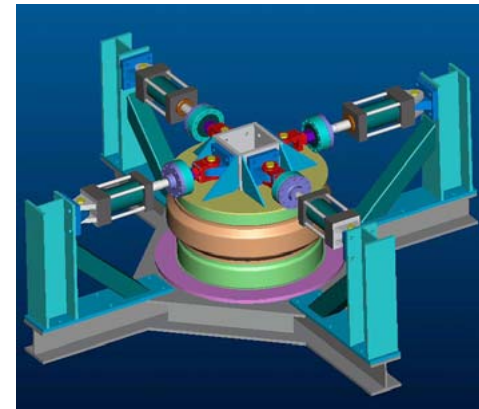
Ballistic Impact Tests: Panels

- Materials screening
- Composite material and failure models



Engine Blade-Out Simulation

- Define ballistic impact test parameters
- Validate analysis methods for certification

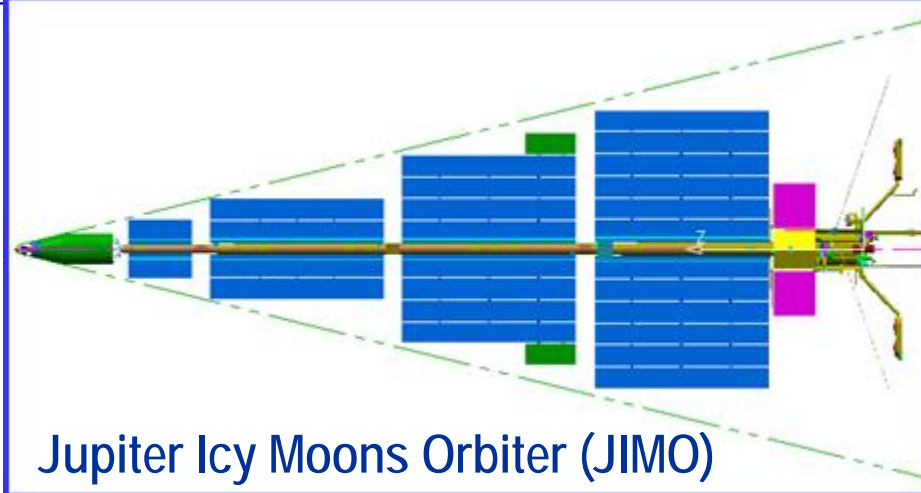


Structural Loading Tests

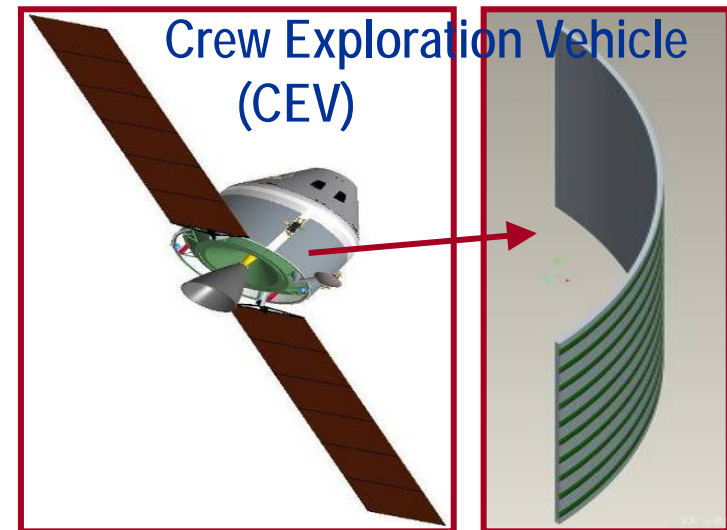
- Simulate rotor out-of-balance loads
- Measures resistance to crack growth



High Temperature PMC Radiators and Heat Exchangers



Jupiter Icy Moons Orbiter (JIMO)



Crew Exploration Vehicle (CEV)

- ✓ Larger area, significant mass driver
- ✓ Wider range of temperatures (200 – 550°F)
- ✓ Sophisticated deployment, possibly similar to ISS



PMC with high thermal conductivity carbon fibers
(Coal tar pitch-based w/ up to 1000 W/mK)
→ Higher potential!

Fission Surface Power (FSP)





Funding Opportunities

- Aeronautics Mission Directorate NRA
 - <http://www.aerospace.nasa.gov/nra.htm>
 - Topics already listed for Supersonics and Subsonics Rotary Wing, Subsonics- Fixed Wing expected soon
- SBIR/STTR
 - <http://nctn.hq.nasa.gov>
 - Phase I- 6 months, \$100K; Phase II – 2 years, \$600K
 - Dates -TBD
 - SBIR Submission Deadlines - Typically Late Summer/Early Fall
 - 2006 deadline for SBIR Phase I proposals was September 7
- Innovative Partnership Program
 - Started in FY06, expect opportunity in FY08
 - Fund partnerships between NASA Center and industry – emphasis on both commercialization and NASA mission needs
 - Up to \$250K funding/year, requires industry and NASA program cost match